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Distribution of Introduced Earthworms in the Northern Jarrah Forest of Western Australia

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Abstract

Five species of introduced earthworm were recorded in the northern jarrah forest of Western Australia during 1980–83. These are *Aporrectodea trapezoides* (Dugès), *A. caliginosa* (Savigny), *Eisenia fetida* (Savigny), *Octolasion cyaneum* (Savigny) (all Lumbricidae) and *Microscolex dubius* (Fletcher) (Megascolecidae). *A. trapezoides* was recorded most frequently.

These introduced species occur within the forest only where there has been major disturbance, especially where forest has been replaced by pasture, orchards or settlement. They have not been recorded in forest that has been logged or in plantations of exotic trees. Introduced species of earthworm were frequently found in association with indigenous species.

Most individuals of *A. trapezoides* kept in jarrah forest soil in the laboratory lost weight over 30 days, in contrast to an indigenous species of earthworm. How and when earthworm species were introduced is discussed in terms of the early European history of the jarrah forest.

Introduction

Apart from taxonomic studies of the indigenous species (Michaelsen 1907, 1911, 1935; Nicholls and Jackson 1926; Jackson 1931; Jamieson 1970, 1971), little is known about the earthworms of the forests of Western Australia. Until recently (Abbott 1981, 1982) the study of the introduced earthworm fauna of these forests was neglected. 'Introduced' refers to species that are not indigenous to Western Australia.

The northern jarrah forest is a large block of forest dominated by one species (jarrah, *Eucalyptus marginata* Donn ex Sm.). It occurs on soils dominated by lateritic gravels and deficient in many nutrients. It is relatively free from permanent settlement or agricultural development. Since 1919 it has been managed under a Forests Act of Parliament. Logging began in the 1870s and most of the forest was cut-over within 60 years. In fertile valleys closer to Perth small areas of forest were cleared for horticulture, orchards, or other types of intensive farming. In addition, timber mills of various sizes were erected throughout the forest in the past. Most of these were abandoned after cutting of the surrounding timber or destruction by wildfires. A few remained, forming the nucleus of small towns.

The aims of this study were: (1) to describe the distribution and frequency of occurrence of introduced species of earthworms in the northern jarrah forest; (2) to relate this to the past degree of disturbance of the forest; (3) to compare

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the growth of an introduced species with that of an indigenous species of earthworm cultured in the laboratory in jarrah forest soil.

Methods

Observational

Localities throughout the northern jarrah forest (Fig. 1) were sampled for earthworms from 1980 to 1983, with most emphasis during winter 1983. Earthworms were hand-sorted from soil to a depth of *c.* 20 cm and later preserved. At first, sampling was restricted to forest stands differing in site quality

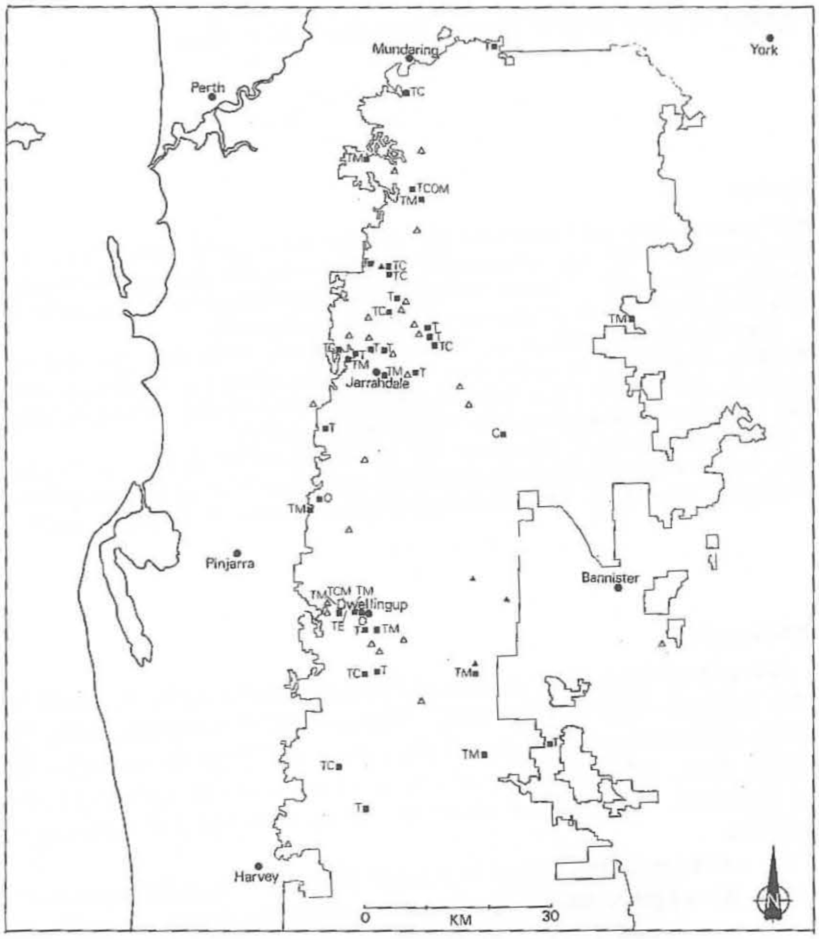

Fig. 1. Known occurrence of introduced species of earthworms in the northern jarrah forest. The location of all disturbed sites that were searched is shown. KEY: ■T *Aporrectodea trapezoides*; ■M *Microscolex dubius*; ■C *A. caliginosa*; △ Indigenous species only; ■O *Octolasion cyaneum*; ▲ none collected; ■E *Eisenia fetida.*

and fire history, but opportunistic observations were made in soil round disused mill sites. It soon became clear that introduced species of earthworm occurred only where there had been marked disturbance of the forest cover and floor. In 1983, therefore, nearly all abandoned settlements that could still be located were sampled.

In winter and spring 1982, four examples of adjacent pasture and forest were selected for more detailed study. Fifteen quadrats ($0 \cdot 036$ m^2) were randomly distributed in each pasture and forest site.

All earthworms collected to a depth of 15 cm were weighed, preserved and later identified. Some textural, physical, and chemical properties of the soils were determined as follows: gravel (>2 mm), coarse sand (0·2–2·0 mm), fine sand (0·02–0·2 mm), silt + clay (<0·02 mm), pH (1:5 w/v soil/water), soil moisture (gravimetric), organic C (modified Walkley–Black), N (Kjeldahl), total P (modified Bray), extractable P (modified Olsen), and extractable K (HNO_3 digest). After the determination of soil moisture, the soil was oven-dried at 105°C. All analyses but gravel and soil moisture were performed on the <2 mm fraction.

Experimental

Soil to depth of 15 cm was collected from beneath a typical stand of jarrah forest in Yarragil block. This topsoil was oven-dried (105°C) and then passed through a 2 mm sieve. A sample of 1 kg of oven-dried soil comprises 590 g of gravel and 410 g of soil. These quantities were used to prepare 20 pots in order to minimize variation in gravel content. The soil was allowed to settle freely into each pot. Each pot was then wetted to 60% water-holding capacity and stored in a cool place. On 28 September 1983, medium-sized immature individuals of *Aporrectodea trapezoides* (mean weight 0·72 g) and an undescribed but readily identifiable indigenous species occurring naturally in the forest soil (mean weight 0·47 g) were selected and weighed. One individual of *A. trapezoides* was placed in each of 10 pots, and one individual of the indigenous species was placed in each of the other 10 pots. Earthworms were reweighed 30 days later.

Table 1. Frequency of occurrence of introduced earthworms in the northern jarrah forest

Family	Species	No. records	Per cent
Lumbricidae	*Aporrectodea trapezoides*	35	55·6
	A. caliginosa	11	17·5
	Eisenia fetida	1	1·6
	Octolasion cyaneum	3	4·8
Megascolecidae	*Microscolex dubius*	13	20·6

Table 2. Associations between introduced species of earthworms in the northern jarrah forest

Species association	No. records	Per cent
A. trapezoides	14	35·9
A. caliginosa	1	2·6
O. cyaneum	2	5·1
A. trapezoides + *A. caliginosa*	8	20·5
A. trapezoides + *E. fetida*	1	2·6
A. trapezoides + *M. dubius*	11	28·2
A. trapezoides + *A. caliginosa* + *M. dubius*	1	2·6
A. trapezoides + *A. caliginosa* + *M. dubius* + *O. cyaneum*	1	2·6
All other combinations	0	0

Results

Observational

Five species were recorded, with *Aporrectodea trapezoides*, *A. caliginosa* and *Microscolex dubius* being most frequent (Fig. 1, Table 1). Most of the possible combinations of the five species were either not found or infrequent (Table 2). The most frequent were: *A. trapezoides*; *A. trapezoides* with *A. caliginosa*; and *A. trapezoides* with *M. dubius*.

Introduced species occurred only where certain kinds of past or present human disturbance were evident (Table 3). Introduced species frequently occurred with indigenous species. Of the 39 localities sampled where introduced species occurred,

Table 3. Incidence of introduced earthworm species and indigenous earthworm species in the northern jarrah forest in relation to degree of disturbance

	Little disturbed[A]	Grossly disturbed[B]
Indigenous species only	96	25
Introduced species only	0	18
Both	0	21

[A] Includes past logging (clear-felling, group selection). The understorey still consists of native plant species and few, if any, introduced plant species.
[B] Includes pasture, orchards, abandoned settlements, towns, pine or eucalypt plantations, picnic areas. The understorey of native species has been entirely or largely replaced by introduced plant species. The original overstorey has also been either removed or reduced to very few native trees.

Table 4. Quantitative features of earthworm population in pasture and adjacent forest in relation to selected soil properties

Grid reference on Forests Department 1:50 000 maps

Feature	Site (P, pasture; F, adjacent forest): P	F[A]	P	F[B]	P	F[C]	P	F[D]
Earthworm species present[E]	A.t. M.d. 1 ind. sp.	2 ind. spp.	A.t. A.c. 1 ind. sp.	3 ind. spp.	2 ind. spp.	2 ind. spp.	A.t. M.d. 1 ind. sp.	1 ind. sp.
Frequency (%)	87·0	67·0	93·3	100·0	33·3	13·3	86·7	46·7
Biomass (g m^{-2})	22·1	13·8	61·3	26·5	8·4	0·3	16·3	2·1
Density (Nos. m^{-2})	75·7	38·8	157·0	90·5	18·5	3·7	62·8	22·2
Date	ix 82	ix 82	viii 82	viii 82	ix 82	ix 82	ix 82	ix 82
Site-veg. type (Havel 1975)	—	TO	—	TU	—	S	—	S
Gravel (%)	36	52			13	20	32	45
Coarse sand (%)	44·8	55·5			70·4	70·8	59·4	60·4
Fine sand (%)	23·7	19·6			19·3	18·7	23·1	25·1
Silt + Clay (%)	29·4	26·9			10·4	12·2	17·2	14·7
pH	6·09	6·34			5·58	5·48	5·35	5·65
Soil moisture (%)	47·3	52·6			11·0	14·8	14·6	15·5
Organic C (%)	4·5	5·2			5·6	5·5	5·4	5·7
Kjeldahl N (%)	0·30	0·33			0·05	0·07	0·11	0·08
Total P (μg g^{-1})	345·6	213·2					75·7	35·4
Extractable P (μg g^{-1})	6·2	2·9			3·2	0·5	2·6	1·2
Extractable K (C/g)	0·73	0·83			0·02	0·06	0·08	0·10

[A] CV 65.7.2 (jarrah/yarri forest). [B] BO 66.7.6 (jarrah/yarri forest). [C] CU 61.5.7 (jarrah forest). [D] BU 65.2.3 (jarrah).
[E] A.t., *Aporrectodea trapezoides*; A.c., *A. caliginosa*; M.d., *Microscolex dubies*; ind. sp., indigenous species.

indigenous species occurred at 21 (or 54%) (Table 3). An additional 25 localities of similar nature (abandoned settlements, pine or eucalypt plantations, picnic areas) yielded indigenous species only.

Introduced species are associated with major disturbance of jarrah forest. Many stands of jarrah forest differing in site quality and fire history were sampled, but no introduced species was ever found in them (Table 3). Nearly all these stands had been disturbed by logging.

Introduced species were found on three of the four pasture sites studied in detail (Table 4). None occurred in adjacent forest. In all cases the biomass and density of earthworms was greater in pasture than the adjacent forest. The major difference in soil properties between pasture and adjacent forest was in total P and extractable P. These were always greater in pasture, consistent with the widespread use of superphosphate as fertilizer in pastures in Western Australia farming (Burvill 1979). However, the pasture in which introduced species were absent had an extremely low level of Kjeldahl N (Table 4), which may have been more limiting than the level of extractable P.

Experimental

Three specimens of the indigenous species and one of *A. trapezoides* died during the course of the experiment. For the indigenous species, the percentage increase in wet weight ranged from $-6\cdot2$ to $57\cdot7$, averaging $17\cdot9$%. For *A. trapezoides*, the percentage increase ranged from $-19\cdot0$ to $+7\cdot9$ and averaged $-7\cdot3$%. This is evidence that *A. trapezoides* would be unable to survive for long in virgin (unfertilized) jarrah forest soil. *A. trapezoides* may not be adapted to the very low organic matter content of jarrah forest soils. The soil used in this experiment had pH of 6·5, organic C of 2·6%, Kjeldahl N of 0·09%, extractable N of 43 $\mu g\ g^{-1}$, total P of 42 $\mu g\ g^{-1}$ and extractable P of 1 $\mu g\ g^{-1}$.

Discussion

Introduced species of earthworms are widespread in the northern jarrah forest but are very localized, being found only in sites disturbed by settlement. This agrees with a study of earthworms on the slopes of Mt Kosciusko, N.S.W., where Wood (1974) found that introduced earthworms occurred only where exotic plants had invaded areas cleared of native vegetation. The finding that indigenous species occur in both little disturbed and grossly disturbed sites agrees with a previous study of earthworms in suburban Perth (Abbott 1982). Indigenous species may be therefore more adaptable than is generally considered (e.g. Stephenson 1930). It seems that virgin soils require some amendment before they are suitable for long-term survival of introduced species of earthworms. In New Zealand, lime, superphosphate and Mo are generally added to newly cleared land (Stockdill and Cossens 1969), whereas in Western Australia superphosphate and various trace elements are used.

This study also agrees with an earlier one (Abbott and Parker 1980) of introduced earthworm species in the wheatbelt of Western Australia. The area studied in that survey is located to the east of the jarrah forest. Most of the wheatbelt has been largely cleared of native vegetation and converted using superphosphate fertilizer to pasture or crops. Both *A. trapezoides* and *M. dubius* were the two species most frequently recorded in the wheatbelt.

The soils of the jarrah forest are poor in nutrients and very gravelly (Havel 1975). They are P-fixing and difficult to plough. Therefore in the days of agricultural expansion they were considered unsuitable for agriculture. Until

recently, extraction of timber was the major widespread disturbance, and involved construction of railways and roads. Before the 1930s horses and bullocks were used to haul logs to depots along the railway lines. The number of beasts used varied with the size of the mill. One of the largest mills used 80–100 horses and 100 bullocks (Ednie-Brown 1896; see also Anon. 1897, 1898). By 1938 tractors replaced horses and bullocks (O'Brien 1938), and trucks after the 1939–45 war replaced the railways.

As the distance that logs had to be transported increased, new mills and settlements were erected throughout the forest from the 1870s. Once the Forests Department was formed (in 1919), forest officers responsible for overseeing the forest were stationed throughout. They were generally supplied with house, shed, stables, cleared and pastured paddock, horse and cart (Stewart, unpubl). Towers to detect wildfires were also constructed during the 1920s and 1930s (Stewart 1941). Gradually, however, with improvements in transportation after 1939 the policy of scattered houses was replaced by one of fewer, small settlements (Stewart, unpubl.).

In the higher rainfall zone close to the metropolitan area, many land grants for farming were made early this century. With the subsequent increase in the population of Perth most of the nearby forest was set aside for protection of water supplies for the expanding metropolitan area. Further alienation (clearing of forest for farming) ceased and existing farms within catchments were resumed by the Government. At present, only 10% of the northern jarrah forest has been cleared for farming or orchards (Darling Range Study Group, unpubl.).

The above historical outline suggests that most introductions of earthworms took place between *c.* 1870 and 1935. Indeed, both *A. trapezoides* and *M. dubius* were recorded within several disturbed parts of the northern jarrah forest in 1905 (Michaelsen 1907). In addition, the year of foundation of certain mills and other settlements can be dated with certainty. These include Whittakers mill (1896, *O. cyaneum*), Loc. 247/183 (1906, *A. trapezoides*), Nanga mill (1908, *A. trapezoides*, *A. caliginosa*), Holyoake mill (1911, *O. cyaneum*), Wuraming mill (1913, *A. trapezoides*, *M. dubius*), Hoffmann mill (1920, *A. trapezoides*), Hakea mill (1926, *A. trapezoides*, *M. dubius*) and Gleneagle forest settlement (1948, *A. trapezoides*). It is most unlikely these earthworm populations could have become established before the years listed.

How were earthworms spread around? I suggest that dispersal involved cocoons in clods of soil adhering to the feet of horses and bullocks, and cocoons and earthworms in pots containing ornamental plants (to establish gardens) and in soil around fruit trees (to establish orchards). The first possibility was considered as 'far-fetched' by Stöp-Bowitz (1969). The second possibility has supporting evidence in that lumbricid earthworms in pots have frequently been intercepted by Customs in several countries (Gates 1972) and have often been found associated with nursery greenhouses in Maine (Gates 1966).

Direct dispersion of introduced earthworms through the jarrah forest by horses and bullocks seems unlikely, as the experiment recorded here indicated poor survival and growth of *A. trapezoides* in jarrah forest soil. The present distribution of introduced earthworms in the northern jarrah forest (Table 3) suggests that their survival was dependent on improvement of soil fertility, necessary for pasture or orchard establishment.

The degree of disturbance experienced at each site where introduced earthworm species were collected was rated on a scale of 1, 2 or 3 where 1 = major disturbance (e.g. removal of jarrah forest with subsequent planting of pines, pasture; abandoned settlement) and 3 = minor disturbance (e.g. soil around a lookout tower). Mean scores were 1·6 (indigenous species only), 1·2 (introduced species only) and 1·1 (both types of species present). This shows that introduced species are associated with major disturbance and also implies that some indigenous species can tolerate major disturbance in contrast to others.

Once established, populations of introduced earthworms have persisted even after the abandonment of active farming or settlement. For example, the following species in some cases have survived for over 30 years: Whittakers mill (closed 1944) — *O. cyaneum*; Hakea mill (closed 1952) — *A. trapezoides*, *M. dubius*; Holyoake mill (closed 1959) — *O. cyaneum*; Nanga mill (closed 1961) — *A. trapezoides*, *A. caliginosa*; Hoffmann mill (closed 1961) — *A. trapezoides*; Loc. 247/183 (abandoned 1968) — *A. trapezoides*; Smailes mill (closed 1970) — *A. trapezoides*, *M. dubius*. No introduced earthworms were found around the site of Jarrahdale Mill No. 2 (abandoned in the 1890s). This may indicate that some of these populations will become extinct within the next 50 years.

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